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Energy services and energy poverty for sustainable rural development

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ABSTRACT

In many rural areas, poor people still depend on wood and other biomass fuels for most of their household and income-generating activities. The difficult, time-consuming work of collecting and managing traditional fuels is widely viewed as women's responsibility, which is a factor in women's disproportionate lack of access to education and income, and inability to escape from poverty. Therefore, it is important for energy access programs to have a special focus on women. New options for energy access and sustainable livelihoods, like small-scale biofuels production, can have dramatic benefits for rural women, and their families and communities. Energy development, as both a driving force and a consequence of such tremendous changes, has had profound impact on economic, social, and environmental development. Rural energy has always been a critical issue due to years of energy shortage for both households and industries. Biomass, for long time, has been the only available fuel in many rural areas. The situation in rural areas is even more critical as local demand for energy outstrips availability and the vast majority of people depend on non-commercial energy supplies. Energy is needed for household uses, such as cooking, lighting, heating; for agricultural uses, such as tilling, irrigation and post-harvest processing; and for rural industry uses, such as milling and mechanical energy and process heat. Energy is also an input to water supply, communication, commerce, health, education and transportation in rural areas.

Contents

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1. Introduction

The absence of commercially supplied energy in a society, especially electricity, tends to accentuate the existence of social asymmetry in conditions of living. This can take the form of increased poverty, lack of opportunity for development, migratory flow to large cities and a society's disbelief regarding its own future. There is a general belief that, with the arrival of electricity, such societies might acquire a higher degree of economic sustainability and a better quality of life [1].

It is estimated that one-third of the world's population, amounting about 2 billions of people around the world, has no access to electric energy. Half of this population lives on the African continent. On the other hand, one of the paths toward economic sustainability refers to the availability of access to regular electric energy. Such access is a key element for the economic development of the rural environment and for the reduction of poverty. However, expanded access to electric energy has shown slow progress worldwide, especially due to the high costs associated with extending grids and developing decentralized systems by which offers power [2].

The public policies whose objective it is to reduce poverty and inequality necessarily permeate education and health matters. Both are directly related to the availability of electricity, mainly insofar as the rural environment is concerned. Electricity is one of the pillars on which education and health lean. As such, the universalization of the access to electric energy in the world is of fundamental importance for the eradication of poverty and reduction of social inequality.

Poverty should be the focus of a range of specific public policies, aimed not only at mitigation, but also at eradication. Lack of access to modern sources of energy aggravates poverty, particularly in the countryside, where opportunities are scarce. The establishment of public policies aimed at the eradication of poverty should include the expansion of access to energy, in particular to electricity, taking into account, mainly, social interrelations [1].

The objectives of this study are to (1) identify problems and difficulties encountered in the social–economic infrastructure as related to rural energy development and (2) present the nonrenewable and renewable energy resources and assess the current energy generation and consumption rates.

2. Energy poverty: the magnitude of the challenge

The excellent economic performance of some regions of the developing world has improved energy access for many communities since 2000. Good progress has been made in East Asia and Latin America, as electricity networks have been extended. But the availability of modern energy in South Asia and Sub-Saharan Africa continues to lag far behind the rest of the world. In Bangladesh, India and Pakistan, for example, 570 million people have no access to electricity, while in Sub-Saharan Africa the number without access has actually risen since 2000, despite a slight increase in the rate of electrification [3].

Most of the world's energy poor are to be found in the rural areas of South Asia and Sub-Saharan Africa. As shown in Table 1, although the number of people without access is greatest in South Asia the lowest electrification rates by far are to be found in Sub-Saharan Africa [3]. Figs. 1 and 2 show electric energy consumption per capita and electricity access in developing countries, respectively.

Lack of access to electricity is not the only problem facing the energy poor. Clean fuels for cooking and general household use are also in short supply. Efficient solutions include liquid petroleum gas (LPG) and kerosene, but these options are often either unavailable or beyond the meagre budget of low-income families. A similar situation exists with regard to gasoline and diesel fuel – both of them highly desirable commodities in rural communities where there are no grid connections. For small farmers, in particular, affordable supplies of vehicle fuel represent an opportunity to transport surplus produce to market and perhaps eventually break away from a subsistence lifestyle. If available at the right price, diesel can fuel generators to drive workshop equipment or power irrigation systems.

The overall scale of energy poverty in Africa and the least developed countries (LDCs) is shown in Table 2 [3]. The consumption of modern energy per capita in these regions is very low in comparison to that of developing countries as a whole. Moreover, the gap between these regions and other developing countries has widened over the past 17 years. In Africa the consumption of modern energy has risen by 3.1% per annum since 1990, but this increase is well below the 3.8% growth rate of economic output.

Without access to modern energy, communities are dependent on traditional biomass such as fuelwood, charcoal and animal waste for cooking and heating. In the least developed countries only 9% of the population cooks with electricity, gas or kerosene; in Sub-Saharan Africa the proportion is 16%. Reliance on biomass is even higher in rural areas. For developing countries as a whole, 83% of rural residents use biomass for cooking. For the LDCs and Sub-Saharan Africa, this proportion rises to over 90%, indicating that even better-off households in rural areas either have no access to, or cannot afford, modern fuels [4].

The most serious consequence of burning biomass in the home is the risk of respiratory and lung disease. According to the World Health Organisation, 1.6 million premature deaths occur each year as a result of indoor smoke inhalation, and more than half of these deaths occur among children under five years of age. As a result of population growth, this problem will continue to worsen. The International Energy Agency (IEA) expects that the number of people depending on biomass for cooking will rise to around 2.7 billion in 2020, from 2.5 billion today. Addressing the multiple challenges of energy poverty will require a variety of solutions, depending on economic conditions and policy priorities. For many hundreds of millions of people, energy poverty is another aspect of overall deprivation [5].

Food and other vital expenditures absorb the greater part of very low incomes. The 40% increases in food and fuel prices since 2005 have put yet further pressure on very tight budgets, leaving little to spend on energy. This low level of effective demand for modern energy makes it uneconomic for power providers to set up the infrastructure needed to supply the fuels, while the lack of supply prevents workshop owners and farmers from improving their productivity and the incomes of the community. This is the "vicious circle" of energy poverty. One way to break the vicious circle is to enhance the purchasing power of potential energy users through microfinance to ease the burden of upfront costs. At the same time,

Table 1
Electricity access in regional aggregates for 2008.

	Population without electricity (million)	Electrification rate (%)		
		Overall	Urban	Rural
Africa	589	40	67	23
Sub-Saharan Africa	587	29	58	12
Developing Asia	809	77	94	67
South Asia	614	60	88	48
All developing countries	1453	72	90	58

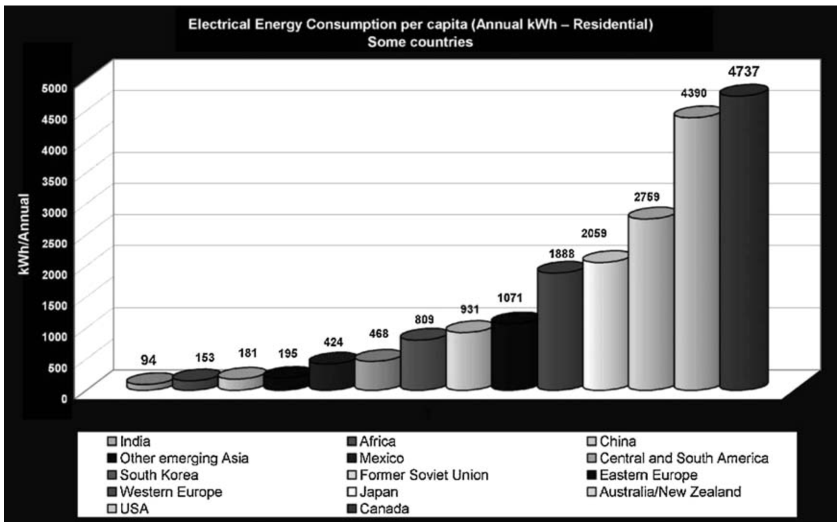

Fig. 1. Electric energy consumption per capita.

initiatives to improve access to markets can boost cash incomes for farmers and traders [3].

Direct support for energy investment can be effective when the community can afford to pay for consumption, but the constraint is the capacity to organize, set up and finance the initial equipment. The UN Millennium Project has developed and costed energy targets which relate to the local needs of households and villages in this situation [3–6].

To achieve these targets, investment would be required to connect all households in urban and peri-urban areas to the grid; to provide access to modern energy for all rural communities; to provide modern fuels for 50% of those households using traditional biomass; and support efforts to make available improved cooking stoves. Based on sample studies, the cost of such a program over a 10-year period would be in the region of 2–3% of annual gross domestic product (GDP).

Such local programs do not include the cost of large-scale electricity generation, transmission or distribution networks or the cost of creating sufficient infrastructure to supply industrial needs. Investment in such infrastructure requires very large commitments of capital. The payback periods are long, and revenues are subject to a wide range of risks. Unless the equipment is actively maintained, the performance of the system will degrade, leading to higher costs and lower standards of reliability [3].

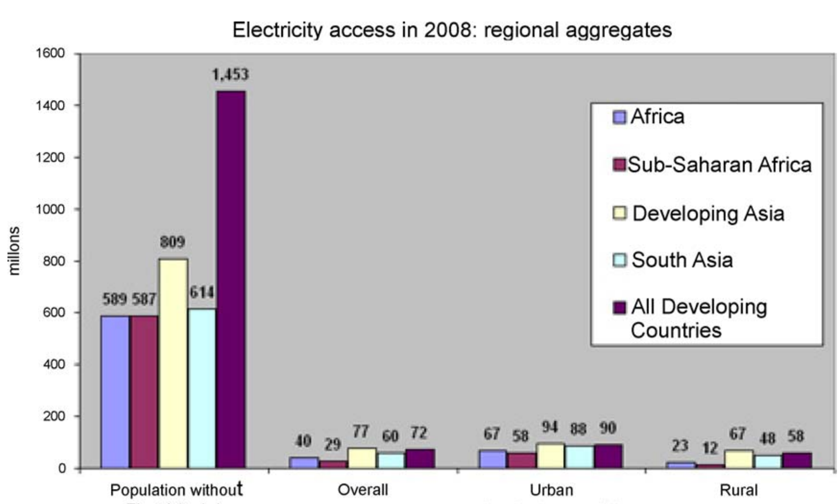

Fig. 2. Electricity access in developing countries.

Table 2
Annual per capita consumption of modern energy (koe).

Region	1990	2007
World	1039	1112
OECD countries	2879	3101
Non-OECD countries	588	678
Africa	188	219
Last developed	52	84

koe: kilogram of oil equivalent.

Table 5
The cost of useful energy (excluding appliance costs).

Energy source	Gross cost ($/kWh)	Cost of useful energy ($/kWh)
Fuelwood	0.01	0.06
Propane	0.05	0.06
Electricity	0.08	0.08
Dry cell batteries	0.59	0.53
Car batteries	2.57	2.31
Kerosene	0.05	5.87
Candles	0.26	13.00

Very substantial investment will be needed to revitalize the generating systems and associated transmissions and distribution networks in the LDCs. According to the World Bank, Sub-Saharan Africa needs to spend 2.7% of annual GDP on capital equipment for the power sector. The IEA has proposed similar estimates. In order to achieve universal electricity access by 2030, Africa and Asia (excluding China) will need to allocate about 3% of annual GDP to investment in the power sector [1–3].

The concept of energy poverty is introduced and linked to the notions of vicious and virtuous circles linking energy services and poverty. The present paper associated with provision of energy services to remote areas and the environmental concerns relating to reducing energy poverty are then addressed. Finally, the paper considers recent development in the debate around energy supply systems. They range from the direct benefits of contributing to increased production and reducing sweat energy, through the contribution that energy can make to health and human capital, through to more intangible benefits of security to a sense of inclusion in the modern economy. Table 3 shows the ways in which these energy services are obtained by different income groups [7,8].

3. Energy efficiency and energy services

Wide ranges of devices convert these primary sources of energy into the various services. The use of energy entails its conversion from one form to another and this always has a cost. The cost of useful energy can be quite different from the cost of the primary energy or fuel. Therefore energy specialists increasingly refer to the provision of energy services rather than merely the supply of energy. Energy conversion efficiencies are illustrated in Table 4. This shows in particular how much more efficient electricity is for lighting than candles and kerosene, and how much more efficient gas is for cooking than wood [9].

If these data are combined with typical energy price data, the impact on people's lives becomes stark. Table 5 shows that nominally high-cost fuels, such as LPG (propane), can be as cheap per meal as fuelwood when providing energy for cooking. It can also be seen why people have a very strong desire to switch from kerosene to electricity for lighting. There is also a strong motivation for people to switch from solid to liquid or gaseous fuels. The replacement of traditional sources of energy with commercialized fuels of increasing efficiency is known as the energy transition. The balance between the various sources of primary energy has changed for all countries as their economies developed. In Europe the transition has been from wind and water, to coal and steam, through to oil and gas. This transition parallels changes at the level of individual energy users [9].

It is important to note that as people become richer and proceed through the energy transition they introduce new, more convenient and efficient sources of energy into their lives, they may well continue using the traditional energy sources as well. This is in part for cultural reasons and in part to minimize the risk of interrup-

Table 3
Typical end uses by energy source in developing countries.

Typical end uses	Income level		
	Low	Medium	High
Household			
Cooking	Wood, residue, dung	Wood, charcoal, residues, dung	Wood, charcoal, LPG, coal
Lighting	Candles, kerosene	Candles, kerosene	Kerosene, electricity
Space heating	Wood, residues, dung	Wood, residues, dung	Wood, residues, dung, coal
Radio/television	None	Grid electricity and batteries	Grid electricity and batteries
Space air-conditioning	None	Electricity (fans)	Electricity, kerosene, LPG
Agriculture			
Tilling	Human labor	Draft animals	Animal, gasoline, diesel
Irrigation	Human labor	Draft animals	Diesel, grid electricity
Processing	Human labor	Draft animals	Diesel, grid electricity
Industry			
Milling/mechanical	Human labor	Human labor, draft animals	Grid electricity, diesel
Process heat	Wood, residues	Coal, charcoal, wood, residues	Coal, charcoal, wood, resid.
Cooling/refrigeration	None	None	Electricity, LPG, kerosene
Services			
Transport	Human labor	Draft animals	Diesel, gasoline
Telephone	None	Batteries	Grid electricity

Table 4
Relative energy conversion efficiencies (typical values).

Cooking		Lighting		Appliances	
Energy source	Efficiency	Energy source	Luminous efficiency	Energy source	Efficiency
Electricity	1.00	Electricity	1.00	Grid electricity	1.0
Propane	0.77	Candles	0.02	Dry cell battery	0.90
Fuelwood	0.15	Kerosene	0.01	Car batteries	0.90

Table 6
Average efficiencies of cookstoves and fuels (%).

Fuel	Stove type	Laboratory data	Field	Acceptable value
Wood	Open fire (clay pots)	n.a.	5–10	7
	Open fire (3 stone)	18–24	13–15	15
	Ground oven	n.a.	3–6	5
	Mud or clay stove	11–23	8–14	10
	Brick stove	15–25	13–16	15
	Portable metal stove	25–35	20–30	25
Charcoal	Mud or clay stove	20–36	15–25	15
	Metal (ceramic liner)	18–30	20–35	25
Kerosene	Multiple wick stove	28–32	25–45	30
	Single wick stove	20–40	20–35	30
	Pressurized	23–65	25–55	40
Electricity	Single element	55–80	55–75	65
	Rice cooker	n.a.	85	n.a.

tion in supply. This multiple fuel use means that the impact of fuel switching and efficiency improvements is often not as dramatic as more simplistic models and policies might predict. This is perhaps at its most extreme with cooking, where households may graduate to LPG but women still use wood and charcoal to cook certain types of food. Even very poor households may retain a variety of options to reduce the costs or risks associated with a particular fuel-technology system [10].

4. Energy services for basic needs

4.1. Cooking

In rural households, energy is needed to meet basic subsistence needs essential for a minimum level of human comfort. These needs consist of cooking, lighting, space-heating, and the operation of household appliances and devices. Of these, cooking energy needs constitute about 80% of the household energy needs in rural areas.

Rural households use a number of different forms of energy to minimize both the costs and the risks arising from unstable supply and technologies. For example, in China, it is not unusual to find households with a solar cooker, biogas ring, and both coal and residue-burning stoves. Even though more than 97% of the villages and 96% of the rural population in China are connected to electricity, there is still a heavy reliance on biomass for cooking and heating. Biomass, either from crop residues or in the form of locally collected fuelwood, provides a cash-free option to the rural poor, whereas electricity may cost as much as 10 times more than in urban areas. For lighting, kerosene is still much in use. Even in households with electricity supply in China, kerosene may be a preferred option because of the cost of grid electricity and the instability of supply [7,10].

Elsewhere in developing countries of Asia, a variety of traditional cookstoves fired by fuelwood, agricultural residue, animal dung, and charcoal are used, with fuelwood being the principal source of supply. The efficiency of traditional cookstoves using fuelwood is low, on average only about 10%. By comparison, the efficiency of stoves based on charcoal is about 20%, whereas the efficiency of those based on commercial energy sources, such as electricity, could be as high as 80% (Table 6) [7].

As stated earlier, the low efficiency of traditional fuels and cookstoves leads to higher smoke discharges and the deterioration of indoor air quality caused by a range of particulate and gaseous emissions. The health risks of indoor biofuel cooking are now well known. In fact, the Bank has classed indoor air pollution in developing countries among the four most critical global environmental problems. The largest direct impacts seem to be respiratory infections in children and chronic lung disease in nonsmoking women. This is one of the few energy-development linkages has been well-documented empirically. Other health impacts of biomass use include those caused by gathering heavy loads of biomass in distant and sometimes dangerous areas. Indirect health impacts from lack of fuel for proper cooking and boiling water may be significant, although difficult to document [11–13].

Fuel and device efficiency considerations, therefore, play a major role in meeting rural cooking energy needs. These could be promoted by upgrading to more efficient fuels, such as biogas, kerosene, LPG, and electricity; by improving the efficiency of current wood stoves; and by introducing more efficient appliances, such as solar cookers [14]. The promotion of efficient biogas digesters and improved cookstoves with an efficiency rating of up to three times that of traditional stoves is a common feature in the rural energy programs of several countries in Asia. In successfully implemented programmers, substantial savings in fuelwood consumption have been achieved [7].

4.2. Lighting

Lighting energy needs in rural households are met mainly by kerosene and electricity. Although electrical lamps are by far the more efficient and offer greater user-convenience compared to kerosene lamps, the choice between the two depends primarily on the extent of saturation achieved in household electricity supply in villages that are connected to the grid. In general, the percentage of villages electrified in a country is a poor indicator of the extent to which the demand for household lighting has been satisfied [4]. This is illustrated in many developing countries where the gap between the number of villages electrified and the number of households connected is often on an order of magnitude. The reasons behind this are the high cost of household connections and high monthly energy charges [10].

Although lighting energy needs in rural households occupy only a small share of their total energy consumption, its importance owes to two factors. First, illumination is without question a fundamental requirement of life, irrespective of class, income, or gender. Second, in poor households, fuels or electricity for lighting are often their main cash expenditure on energy, and the proportion of this expenditure in the household budget can be significant.

4.3. Other household applications

The use of household appliances, such as rice cookers, fans, radios, and television sets, depends first on the availability of electricity and second on the income levels of the rural population *vis-à-vis* the costs of acquisition of such appliances. In fact, the poor's lack of purchasing power to own appliances is a major inhibiting factor in rural equity [15,16].

It is argued at times that the uses to which such household appliances are put are not necessarily to meet their basic needs. Isolation from the rest of the society is more often than not a central characteristic of rural communities in general, and those in remote areas in particular. From their perspective, the ability to own and use a television set is a basic need to acquire a sense of belonging to the mainstream of development [10]. The same may be said of several other household appliances of convenience that help reduce the labor intensity of rural life and allow people to redirect the time saved to other activities for self-improvement or economic betterment. Arguments to the contrary reflect a value judgment that can be challenged on the grounds of dualism [17–22].

4.4. Community uses

Community uses for energy include public lighting, water-pumping, lighting, and appliances in health clinics and schools, and the requirements of common facilities for social interaction. Electricity is the most critical source of energy to meet these needs and if its absence, other forms of energy like kerosene are used. Energy to meet these essential community services is a part of the package of public benefits that governments are expected to provide rural populations. It is just as critical as energy for household needs as described above because many of the core conditions of poverty often stem from inadequate community services, and a number of these services cannot be dealt with at the level of isolated households [23–30].

In absolute terms, and based on the technological options already available, ensuring the basic energy needs of the rural people is not an insurmountable problem. According to the World Energy Council [25,30], it has been estimated in India "that about 948 MJ of useful energy is needed per capita per year to meet cooking energy needs. Similarly, about 46 MJ of useful energy per capita per year is required to meet space heating needs, and the same amount again, 46 MJ of useful energy per capita per year, is needed to meet lighting needs. Thus, a total of some 1039 MJ of useful energy per capita per year is assumed to be required at the household level to meet the three basic energy services such as cooking, lighting, and space heating. Taking the Indian minimum useful energy norm as a basis, and multiplying it by the total developing country rural population in 2008 of 3.1 billion people, we would find their total annual useful energy requirement to be 3575 PJ. If we were to stretch our imaginations and suppose that these energy needs could all be met by electricity, assuming an 85% conversion efficiency of the electrical appliances used, this would translate into 3672 PJ.

5. Energy services for income generation

5.1. Agriculture

Rapid agricultural and economic growth was the driving force behind the dramatic reduction in poverty in most of Asia. Agricultural growth that raises agricultural productivity and the returns to farm labor has been particularly important in reducing poverty because of the high concentration of poverty in rural areas and the dependence of many of the poor on the farm sector for their incomes [7,10,13].

Energy statistics do not show agricultural activities as major energy consumers in rural areas, mainly because the energy involved in them consists largely of human and animal labor. Modern energy services essential to increase agricultural productivity and income invariably substitute the labor content of production, a fact that is frequently overlooked in traditional approaches to rural energy analyses. The energy needs of agriculture consist of (a) direct energy needs for land preparation, cultivation, irrigation, harvest, post-harvest processing, storage, and the transportation of agricultural inputs and outputs; and (b) indirect energy needs in the form of fertilizers, weedicides, pesticides, and insecticides [28].

Much of the direct energy inputs into agriculture is usually in the form of human and animal labor. Modern energy, such as electricity and diesel, replaces labor for irrigation water-pumping, mechanization of agriculture, and transportation of agricultural products [29–31]. Agricultural mechanization involves mainly the use of diesel for tractors, tillers, threshers, and other farm equipment, and the use of electricity in irrigation pump-sets. In general, irrigation needs are the primary targets of grid-based rural electrification [23–25].

Indirect energy inputs form on average nearly half the total energy consumed in agriculture, and the expenditure on modern energy inputs crucial for agricultural productivity, such as chemical fertilizers, is a substantial cash outflow for rural people. The very poor among them who cannot afford these inputs fall back on natural fertilizers like agricultural residue which has the effect of curtailing the productivity of the land and, therefore, income from it. Often, in areas of a scarcity of wood supply, it also poses critical tradeoffs in the use of agricultural residue as a fuel, fodder, or manure [7].

5.2. Rural industries

Population pressures on finite agricultural land invariably impel a gradual extension of rural economic activities into nonfarm enterprises, broadly defined as rural industries [2]. The development of rural industries is thus an essential component of rural economic transformation, not only to supplement agriculture-based incomes but also, in the larger context, to arrest rural–urban migration [1–4].

Available definitions of rural industries vary by country according to the criteria employed, such as the size of capital invested, strength of the labor force employed, production volume, and the use of modern energy sources. Often large-scale industrial facilities, such as sugar and palm oil factories, are sited in the rural areas side by side with medium- and small-scale industries. In addition, there are usually large numbers of household enterprises operated as family businesses on a microscale [11].

In general, rural industries can be broadly classified into agro-based and nonagro-based industries. The former would consist of such facilities as those for rice-milling, fruit and vegetable processing, tobacco-curing, and a range of skill-based household businesses, whereas the latter would include charcoal and brick manufacturing facilities, potteries, bakeries, blacksmithies, woodworks, and village workshops. Shops and establishments that do not fall under either of these categories form the services sector [10].

The energy needs of rural industries comprise lighting, process heat, and motive power. Lighting requirements are invariably met by electricity in electrified villages and by kerosene in unelectrified villages. The principal supply sources for process heat in facilities, such as blacksmithy, brick-making, and charcoal manufacture, are fuelwood and biomass. Motive power requirements are met by electricity, where it is available, and by human labor using mechanical equipment, where it is not. In agro-based facilities, such as crop-drying and rice-milling, the use of biomass is widespread [9].

Rural electrification and the greater availability of commercial fuels in the rural areas induce a steady transition from traditional to commercial sources of energy supply in developing countries—subject to the crucial condition of economic capacity. Improving the efficiency of heating equipment, such as boilers, furnaces, and dryers, is thus an important element of the strategy to meet the energy needs of this sector. Substantial opportunities for self-generation and cogeneration based on biomass also exist

Table 7
Energy-related livelihood strategies.

Livelihood strategy	Means
Gaining additional income by retailing energy services up the "energy ladder"	• Fuels (wood, charcoal, dung, crop residues, kerosene, LPG) • Conversion technology (stoves, lamps, batteries, motors, PV systems)
Gaining access to improved energy services at the household level by saving time, or fuel switching	• Improved biomass stoves • Improved lighting (from candles to kerosene to electricity initially from batteries)
Gaining access to improved energy services, by increasing production efficiency	• Improved energy services result in increased productivity (e.g., through mechanization), which results in a greater ability to pay for improved energy services. Opportunities range from the lowest technologies and the smallest scales upwards (for example, agro-processing, small and microenterprises)
Grouping with others to obtain access to improved energy services, for production, household consumption or for community services (health centers, schools, security lighting, and information and communication technology)	Community-based activities enable labor to be converted into capital (e.g., through civil works) and capture the economies of scale associated with energy supply technologies, such as connecting to the grid (transformers and distribution systems) and installing microhydro generators, small diesel engines or acquiring mechanized transport services, and the like, or "pooling demand" to provide political or commercial pressure to gain access to energy services

in facilities that have combined requirements of both steam and electricity [8].

5.3. Livelihood activities of the poor

Within the broader context of rural economic activities, the poor are usually limited to agriculture and to its allied activities, such as animal husbandry, poultry, fishery, and vegetable and fruit cultivation. The bottom poor among them who own no land of their own are even more restricted in their economic options. The poor's ability to generate income through activities other than these, for instance, through microenterprises, is constrained by several factors of which energy is one. Even if modern energy services were available and affordable to poor households, the absence of roads, communication, access to market, and credit pose formidable barriers for them.

Poor households and individuals adopt livelihood strategies that consist of a variety of both market-oriented and nonmarket-oriented activities. The aim of these strategies is to sustain and, if possible, improve their situation by appropriate use of their stock of assets, both material (physical and financial capital) and non-material (human and social capital). Poverty reduction implies the accumulation of assets over time. This can lead to both improved living standards and/or an increase in the range of possible future livelihood strategies. In difficult periods, it may be necessary to draw on the stock of assets to maintain minimum living requirements [12].

Focusing on the livelihoods of the poor provides a means whereby the balance between "productive" and "social" uses of energy can be understood. Both can be seen as the utilization of energy services to increase asset holdings—in one case economic, in the other human or social. To understand the potential role of energy services in poverty reduction, it is essential to have a clear understanding of the livelihood strategies currently adopted. This is necessary to determine if the lack of access to specific energy services may be constraining the range of livelihood strategies available to the poor, reducing both incomes and the possibilities for asset accumulation. Energy-related livelihood strategies for the poor and their potential outcomes are illustrated in Table 7 [10].

6. Rural electrification and rural socioeconomic development

As mentioned in Section 1, in spite of its relatively small share of the aggregate rural energy supply, electricity is viewed as symbolic of rural development itself. The unavailability of electricity is among the most visible signs of rural–urban and rural rich–poor socioeconomic gaps. The harshest criticisms of conventional approaches to rural energy development are often based on the shortcomings of rural electrification programs.

The crux of the rural electrification dilemma is that electricity is an expensive, high-quality energy source that practically all rural people want but only some can afford, subject to the overriding condition of its availability in the first place. Although other goods and services are equally expensive and, therefore, just as much outside the reach of the rural majorities, the case of electricity is special because it is identified with basic needs issues and notions, such as universal access, lend it a distinct human development role. This makes rural electrification a socially and politically sensitive topic [20].

Electricity is expensive due to involve capital-intensive technological interventions to transform a primary energy resource from its natural state to useful energy. It is considered qualitatively superior because of its ability to meet almost the entire range of energy end-uses, something that no other energy form can. In order to recover the initial investment and the running costs of an electric supply system over its lifetime, an appropriate pricing structure is needed. Market economic theory presents a persuasive reasoning for electricity to be priced in a way that reflects its scarcity and makes full cost recovery possible. Unfortunately, in most situations, what is considered a cost-recovering scarcity price lies beyond the average income levels of rural populations. Welfare-oriented development doctrines, therefore, militate against the notion of market prices for electricity on the grounds that they would inhibit rural socioeconomic development, the benefits of which cannot be measured in financial terms alone [4,7,10,13].

National power utilities are caught in the middle of this argument. On the one hand, in order to obtain the necessary capital for supply expansion and stay in business, they have to operate on financial viability principles. On the other hand, because most utilities in the developing countries are state-owned, they are compelled to respond to social and political pressures by subsidizing electricity prices. In their attempts to appease these opposing forces, utilities have generally struggled to satisfy both.

During the past two decades, it has been the hope that the problems of grid electrification by utilities could be overcome by shifting to a strategy of decentralized rural electrification based on renewable energy technologies. In spite of concerted efforts to promote these technologies, however, their share of the aggregate rural electricity supply remains a small fraction of it, less than 1% in the majority of developing countries. Although decentralized electricity options have a number of distinct advantages, they also suffer from certain unique disadvantages, important among which are their high initial investment costs and the intermittent nature of

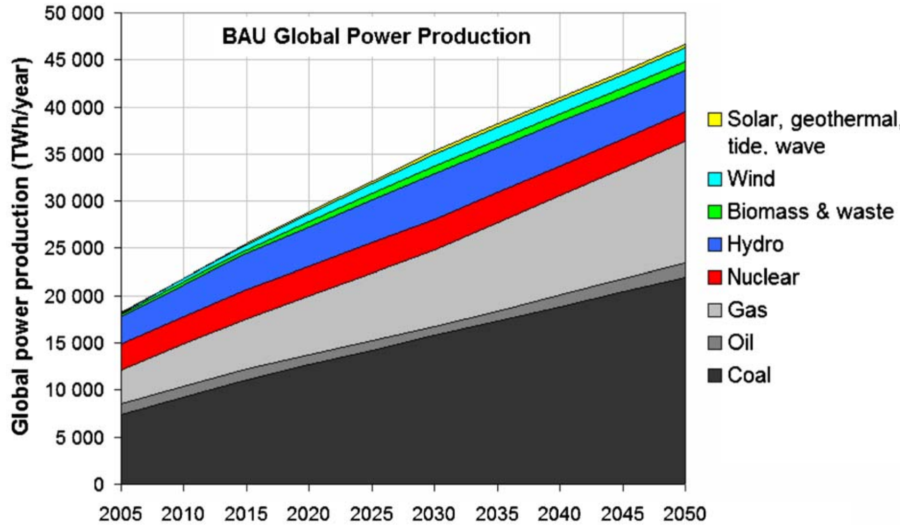

Fig. 3. Business as usual scenario for power production.

electricity supply from them. As a result, their contribution to rural electrification has faced its own distinct hurdles.

According to a World Bank report [23]: "One of the most persistent claims for rural electrification (RE) is that it can induce industrial growth in otherwise lagging low-income rural economies. The evidence from developing countries does not support this claim; RE has not, by itself, triggered industrial growth or regional development. The study found that where other prerequisites of sustained development were absent, demand for electricity for productive uses did not grow. RE is economically justified only when the emerging uses of electricity are strong enough to ensure sufficient growth in demand to produce a reasonable economic rate of return on the investment. RE may be in a unique position to promote a paradigm shift in agricultural production, by making possible irrigation and associated modern technology and practices."

This builds up an image of rural electrification primarily associated with social welfare. A significant number of rural areas, most of them poor, do not get access to the main grid. Even in electrified areas, a poor households are not connected. Utilities perceive rural electrification as a social obligation and an economic constraint that they are not able to face alone anymore. Populations and politicians consider electricity as a social right that must be dealt with. Electrification is a priority and insufficient electrification rates are seen as social injustice, or a failure of energy policy and national utilities. This alone justifies rural electrification to be more prominently included in poverty reduction strategies [10].

Another interpretation, however, more narrowly links rural electrification with productive development and reinforces its character of priority, not only for social, but also for economic, reasons. If rural populations realize a better life through access to electricity, they do not get it for free. They have to pay for access and consumption to the best of their ability, and that in itself could be the major economic impact of electrification. Electricity is a market and value builder, pulling rural dwellers into the consumption world. Clear, direct impacts are linked to the payment of electricity bills and investments in electrical equipment and appliances. Qualitative evaluations and surveys suggest that there is also an indirect impact on nonproductive household investments and deeper consumption pattern changes. Economic development then relies on contributions from the community to the overall economy, and to a lesser extent on contributions from surrounding areas to the

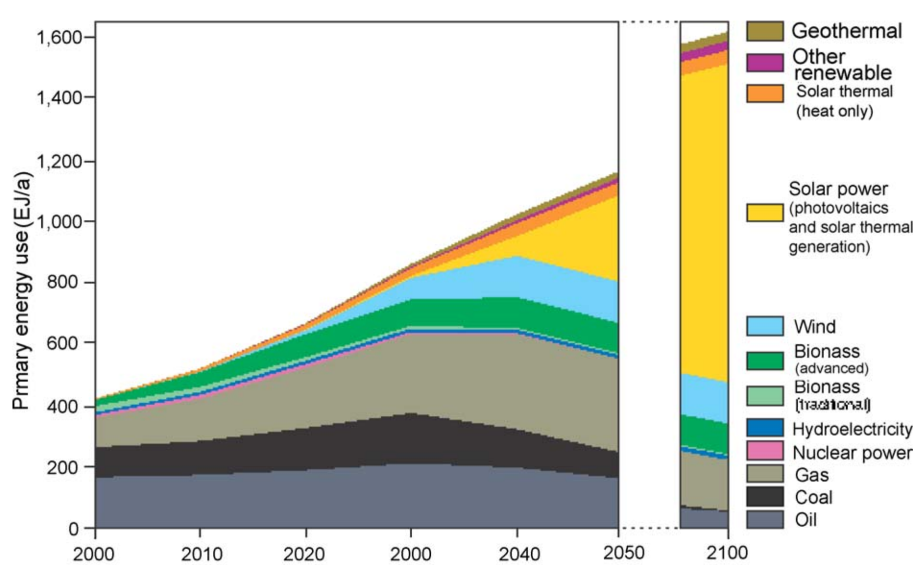

Fig. 4. Expected growth in global energy sources.

community—in a process that mainly drains financial resources from rural to urban areas [7–13].

Investments and consumption will have impacts more external than internal to the rural community. Market development rather than increased energy availability will also be responsible for the collateral emergence of village activities, such as the development of paid housework, cottage industries, and small commerce. The transformation of the rural economy will, in turn, have social consequences, not all of them positive, as newly concentrated modern activities will suppress more traditional ones. Electrification monetizes village economies; the downside is that it also monetizes poverty.

7. Conversion of renewable energy

It is also important to note in this context that all modern renewable energy technologies share a particular characteristic that often limits their use by poor people: They have high initial capital costs and low recurrent (fuel) costs relative to fossil fuel-based technologies. This is particularly so for photovoltaic electricity, hydropower, and wind energy. The poorer the people, the less likely it is they can afford this kind of renewable energy. For this reason, poorer people often pay more per unit of energy used simply because they cannot afford the initial costs of supply options that have the lowest lifetime cost. Similarly, where generating utilities have very severe limits on capital expenditures, their opportunity cost of capital at the margin rises to very high levels. They will then commonly opt for technologies with a lower initial capital cost, such as diesel generators, over an apparently preferable renewable option, such as micro hydropower [14–20]. Figs. 3 and 4 also show global power production and expected growth in global energy sources, respectively.

7.1. Biomass

Modern biomass as fuel for power, heat, and transport has the highest mitigation potential of all renewable sources [16–18]. It comes from agriculture and forest residues as well as from energy crops [14]. The biggest challenge in using biomass residues is a long-term reliable supply delivered to the power plant at reasonable costs; the key problems are logistical constraints and the costs of fuel collection. Energy crops, if not managed properly, compete with food production and may have undesirable impacts on food prices. Biomass production is also sensitive to the physical impacts of a changing climate [5,6,21].

Projections of the future role of bio mass are probably overestimated, given the limits to the sustainable biomass supply, unless breakthrough technologies substantially increase productivity. Climate-energy models project that bio mass use could increase nearly fourfold to around 150–200 EJ, almost a quarter of world primary energy in 2050 [8]. However, the maximum sustainable technical potential of biomass resources without disruption of food and forest resources ranges from 80–170 EJ a year by 2050 [9], and only part of this is realistically and economically feasible. In addition, some climate models rely on biomass-based carbon capture and storage, an unproven technology, to achieve negative emissions and to buy some time during the first half of the century [22–25].

Some liquid biofuels such as corn-based ethanol, mainly for transport, may aggravate rather than ameliorate carbon emissions on a life-cycle basis. Second-generation biofuels, based on lignocellulosic feedstocks such as straw, bagasse, vegetative grass, and wood hold the promise of sustainable production that is high-yielding and emits low levels of greenhouse gas, but they are still in the R&D stage.

7.2. Solar

Solar power, the most abundant energy source on Earth, is the fastest-growing renewable energy industry. Solar power has two major technologies; solar photovoltaic systems and concentrated solar power. Solar photovoltaic systems convert solar energy directly into electricity. Concentrated solar power uses mirrors to focus sunlight on a transfer fluid that generates steam to drive a conventional turbine. Concentrated solar power is much cheaper and offers the greatest potential to produce base-load, large-scale power to replace fossil power plants. But this technology requires water to cool the turbine; a constraint in the desert, where solar plants tend to be installed [26]. So expansion is limited by geography (because concentrated solar power can only use direct beam sunlight) as well as by the lack of transmission infrastructure and large financing requirements. Solar photovoltaics are less location-sensitive, quicker to build, and suitable for both distributed generation and off-grid applications. Solar water heaters can substantially reduce the use of gas or electricity to heat water in buildings. China dominates the global market of solar water heaters, producing more than 60% of global capacity [26,27].

At current costs, concentrated solar would become cost competitive with coal at a price of $60 to $90 a ton of CO_2 [16,28]. But with learning and economies of scale, concentrated solar power could become cost competitive with coal in less than 10 years, and the global installed capacity could rise to 45–50 GW by 2020 [14,15]. Similarly, solar photovoltaics have a learning rate of 15–20% cost reduction with each doubling of installed capacity [23]. Because global capacity is still small, potential cost reductions through learning are substantial.

7.3. Wind, hydro, and geothermal

Wind, hydro, and geothermal power are all limited by resources and suitable sites. Wind power has grown at 25% a year over the past five years, with installed capacity of 120 GW in 2008. In Europe more wind power was installed in 2008 than any other type of electricity-generating technology. But climate change could affect wind resources, with higher wind speeds but more variable wind patterns [17,18].

Hydropower is the leading renewable source of electricity worldwide, accounting for 16% of global power. Its potential is limited by availability of suitable sites (global economically exploitable potential of 6 million GWh a year) [16] large capital requirements, long lead times to develop, concerns over social and environmental impacts, and climate variability. More than 90% of the unexploited economically feasible potential is in developing countries, primarily in Sub-Saharan Africa, South and East Asia, and Latin America. Africa exploits only 8% of its hydropower potential [24].

For many countries in Africa and South Asia, regional hydropower trade could provide the least-cost energy supply with zero carbon emissions. But the lack of political will and trust and concerns about energy security constrain such trade. And greater climate variability will affect the hydrological cycle. Drought or glacial melting could make hydropower supplies unreliable in some regions. Nevertheless, after two decades of stagnation, hydropower is expanding, particularly in Asia. But the current financial crisis makes it more difficult to raise financing to meet the large capital requirements [29].

7.4. Smart grids and meters

With two-way digital communications between power plants and users, smart grids can balance supply and demand in real time, smooth demand peaks, and make consumers active participants in the production and consumption of electricity. As the share of

Table 8
Additional number of people needing to gain access to modern fuels (millions).

	Between 2004 and 2015	Between 2015 and 2030
Sub-Saharan Africa	314	406
North Africa	2	3
India	389	394
China	226	168
Indonesia	85	94
Rest of Asia	261	300
Brazil	13	14
Rest of Latin America	30	28
Total	1320	1407

Table 10
Electrification rates by region (%).

	1970	1990	2000	2015	2030
North Africa	34	61	90	98	99
Sub-Sahara	9	16	23	33	49
South Asia	14	25	34	43	56
Africa	17	32	41	53	66
Latin America	45	70	87	94	96
East Asia/China	30	56	87	94	96
Middle East	36	64	91	97	99
Developing countries	25	46	64	72	78
World	49	60	73	78	83

generation from variable renewable resources such as wind and solar increases, a smart grid can better handle fluctuations in power. It can allow electric vehicles to store power when needed or to sell it back to the grid. Smart meters can communicate with customers, who can then reduce costs by changing appliances or times of use [30].

8. Biofuels for sustainable rural development

When we began considering local production of biofuels as a possibility for expanding access to energy in developing countries, there was much enthusiasm about the idea of homegrown energy [30], especially for rural areas where villagers are already engaged in small-scale agriculture. United Nations studies show that available energy systems fail to meet the needs of poor communities, with 2.4 billion people relying on traditional biomass (wood, charcoal, dung and agricultural residues) and 1.6 billion without access to electricity [1]. With prices for fossil fuels remaining high, and energy infrastructure investments for poor countries primarily focused on urban areas and industrial development, many people in rural areas are being left without basic energy services. Table 8 shows additional number of people needing to gain access to modern fuels [5,14].

Gender considerations come into play because in many developing countries the current lack of energy in rural areas has a disproportionate impact on women. They are the ones primarily responsible for collecting and managing traditional biomass fuels. Table 9 shows comparison of characteristics of traditional and modern biomass fuels. The long hours and distances travelled by women gathering wood or dung, carrying water, growing crops, processing food and caring for their families all without electricity, motorized equipment or modern fuels generating activities that could help lift them, their families and their communities out of poverty. Table 10 shows electrification rates by region [5].

In addition, women are the main producers of food crops in many areas. If these women could grow oil-producing crops, sell them for income, and also use the oil for motorized power, electricity generation, household activities and profitable enterprises, this could open up exciting new opportunities for local economic development. Studies have shown that women can also profit by establishing and sharing in bioenergy processing operations.

8.1. Sustainability of biofuels

Biofuels soon were being viewed with less enthusiasm. Controversy erupted over sharply rising food prices, amid concerns that the diversion of agricultural production from food to biofuels was responsible, at least in part, for food shortages in countries already suffering from widespread poverty and hunger. United States subsidies for production of ethanol from corn came under attack, along with European Union policies promoting the use of biofuels for transportation. In Africa, civil society groups and unions called for removal of some food crops from the biofuels feedstock mix [14,21].

In addition to exacerbating food shortages and poverty, biofuels were being linked to deforestation, neocolonialism associated with the establishment of biofuels plantations on huge tracts of land in developing countries, and displacement of small farmers and indigenous people from their lands – as well as increased production of greenhouse gas emissions, due to the loss of trees and the use of fossil fuels in planting, fertilizing, harvesting and processing biofuels.

There were also concerns that women would be disproportionately affected by large-scale biofuel production if they were to lose access and rights to land and resources they relied on for collecting fuel and water for household needs, growing food, and gathering fodder, medicinal plants and wild food. An FAO report [31] warned that the potential environmental and socioeconomic risks associated with large-scale production of liquid biofuels in developing countries might affect men and women differently, particularly due to inequalities in terms of access to and control over land and productive assets. In South Africa, for example, women smallholder farmers questioned whether men with larger farms would be favoured as suppliers of feedstock for biofuel processing operations, and more broadly whether women and other small farmers would be left out of the more profitable parts of the value chain of biofuels production [31].

Much international attention turned towards defining 'sustainable' production of biofuels, and a number of different processes

Table 9
Comparison of characteristics of traditional and modern biomass fuels.

Characteristic of technology	Traditional	Modern
Fuel	Mostly gathered or collected and in some cases purchased	Commercially procured
Capital	Low capital cost	High capital cost
Labor	High labor intensity at household level in collection of fuel	Low labor intensity at household level but overall high labor intensity compared to other energy sources
Conversion process	Low efficiency and poor utilization of biomass	Higher efficiency and higher utilization of biomass
Energy uses	Energy for cooking and heating in poor households in developing countries	Commercial heating, electricity and transportation
Emission controls	Poor emission controls	Controlled emissions
Co-product	No co-products	Commercially useful co-products

were initiated to discuss standards and criteria for sustainability in relation to biofuels. Although earlier discussions focused on the benefits of biofuels in reducing overall greenhouse gas emissions from transportation vehicles, due to the growing concerns over food security and displacement of people from their traditional lands, calculations about biofuel production began to take a broader view. Social impacts began to be more closely analyzed and taken into account, in addition to impacts on biodiversity, ecosystems, soil degradation and water scarcity [21].

The multi-stakeholder process organized by the Roundtable for Sustainable Biofuels produced draft criteria that included an emphasis on protection of land rights, water rights, human rights and labor rights, as well as transparent, consultative and participatory processes for planning biofuels projects. The draft principle on rural and social development states that: "Biofuel production shall contribute to the social and economic development of local, rural and indigenous peoples and communities". Still, even when social impacts of biofuels programs are considered, women's particular concerns are rarely emphasized. In order to address this gap, it is recommended that environmental and social impact assessments of proposed biofuels projects or programs should include an evaluation of gender-differentiated impacts and that gender equity should be one of the principles considered in those assessments [8].

After reviewing information about a variety of different biofuels projects, it seems that village level projects have great potential in terms of sustainable fuel production and increased access to energy in rural areas of developing countries – if participatory processes are employed in the development and implementation of the projects. On a small scale, locally produced plant oils and biodiesel can successfully be used to power diesel engines and generators in rural villages – for agricultural processing, new enterprises, and income generation. These systems can also ease the burdens of women and foster women's participation in decision-making processes. Moreover, although most of the threats related to biofuel production come from the operations of big plantations run on an agro-business model, it also does seem possible to try to protect the interests of small landowners and engage them as producers and processors of biofuels as part of a larger value production and supply chain [1–5].

9. Environmental aspects of reducing energy poverty

Environmental impacts are both a driving force in raising awareness of issues of energy and poverty but they also form a major constraint to action. The huge impact of indoor air pollution caused by the burning of solid fuels, particularly biomass, on the health of women and children has been mentioned already. Similarly, the collection and burning of woody biomass can have effects on ground cover, and the burning of dung can affect the level of nutrients being returned to the soil. But the link between the energy uses of biomass and deforestation varies from location to location. In principal biomass can be a renewable energy resource, but there are areas of fuel pressure where the use of the biomass is more akin to nonrenewable mining [23–25].

In a significant number of cases the energy options that best meet the needs of poor people will involve fossil fuels, and their use can have a negative effect on the local and global environment. There are very few alternatives to fossil fuels for transport and the cheapest electricity for most people will come from large power stations fuelled by gas, coal, or oil. Even in remote rural areas, diesel engines will provide the optimal solution for providing both shaft power and electrical power for machines. There is therefore an evident tradeoff between the objective of tackling energy poverty and the objective of improving the environmental problems linked to energy conversion and use [10].

If the primary objective is meeting the energy needs of the not-served and underserved populations, neither the optimal solutions nor the most equitable solutions will be found if their energy options are restricted just to renewable sources. The move toward empowerment as a development objective implies that people in power should allow the excluded majority to make informed choices from the full menu of energy options, so they can select the option that best meets their needs. They certainly cannot be expected to restrict their options willingly while northern industrial countries are not doing enough to reduce the pollution burden of their current and past energy consumption [9,12].

The complexity of the arguments over renewable and nonrenewable energy options is well illustrated by a particularly important finding from recent empirical research. This suggests that if the people who are currently cooking by inefficiently burning renewable fuelwood were to switch to nonrenewable gas (LPG) there would be a strongly positive environmental impacts and a massive reduction in green house gases per person meal [29]. Simplistic assumptions as to the relative merits and demerits attaching to renewable and nonrenewable energy sources can be very misleading, and lead to damaging policy responses.

10. The role of intermediation

Experience during the past 25 years demonstrates that at the heart of the problem of developing decentralized energy supply options are the very high costs associated with putting together the various elements of technology, finance, community development, and management required to make such schemes work [4]. For many of the larger schemes, many hundreds of tasks are necessary to get them off the ground and running sustainability. A number of analysts have found that the idea of intermediation offers a convenient way to group and understand these activities. The approach extends the idea of financial intermediation and considers three additional forms of intermediation: technical, social and organizational intermediation. Financial intermediation involves putting in place all the elements of a financial package to build and operate a decentralized energy supply company in place. A process sometimes referred to as financial engineering [32].

Technical intermediation involves improving the technical options by undertaking research and development activities, and importing the technology and know-how down through the development of capacities to supply the necessary goods and services. These goods and services include: site selection; system design; technology selection and acquisition; construction, and installation of civil, mechanical and electrical components; operation; maintenance; trouble shooting; overhaul; and refurbishment [33].

Organizational intermediation involves not only the initiation and implementation of programs, but also lobbying for the policy change required to construct an environment of regulation and support in which the energy technology and the various players can thrive. This involves putting in place the necessary infrastructure and getting the incentives right to encourage owners, contractors, and financiers. Organizational intermediation must include the development of regulatory support and incentive structures that can specifically address the energy needs of the poor and women, particularly in rural areas [20].

11. Conclusions

Energy services for poverty reduction are less about technology and more about understanding the role that energy plays in people's lives and responding to the constraints in improving livelihoods. In the past, dissemination programs have tended to concentrate on the supply of energy, such as electricity or

petroleum, or on energy technologies, such as solar equipment or improved stoves. Energy needs should be considered within the overall context of community life, and energy policies and projects should be integrated in a holistic way with other improvement efforts relating to health, education, agriculture and job creation. Policies, programs and projects should start from an assessment of people's needs rather than a plan to promote a particular technology. The needs of different rural communities vary widely, and finding appropriate technologies and effective implementation strategies can be very site-specific. As a result; energy is needed for household uses, such as cooking, lighting, heating; for agricultural uses, such as tilling, irrigation and post-harvest processing; and for rural industry uses, such as milling and mechanical energy and process heat. Energy is also an input to water supply, communication, health, education and transportation in rural areas.

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